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*This article is based on studies supported principally by a grant of the Ford Foundation, which has sponsored Industrial Dynamics Research at M.I.T., and in part by a grant of the National Aeronautics and Space Administration to sponsor research on the management of research and development. The computer simulations were carried out at the M.I.T. Computation Center. The writer is grateful to Professors Donald C. Carroll, Jay W. Forrester, and Donald G. Marquis, for their many helpful comments.

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INDUSTRIAL DYNAMICS AND THE DESIGN OF MANAGEMENT CONTROL SYSTEMS

Abstract

The usual approaches to management control system design often fail to be effective, sometimes creating problems more significant than those they resolve. Such failures result from lack of total system understanding, from use of subsystem boundaries, and from inadequate or improper treatment of the human decision-making elements of the system. Examples drawn from Industrial Dynamics research studies illustrate these problems and provide some pointers for resolving the difficulties.

I. The Organization as a Control System

Every organization is a control system. Each has direction and objectives, whether explicit or implied. Each has beliefs as to its current status. Each has policies and procedures whereby it reaches decisions and takes actions to attain its goals more closely. Every organization actually contains a myriad of smaller control systems, each characterized by the same goal-striving, but not necessarily goal-attaining, behavior.

The organization as a whole or any one of its component subsystems can be represented by the feedback process shown in Figure 1. Four characteristics of this diagram are noteworthy. First, the transformation of decisions into results takes place through a complex process which includes a basic structure of organizational, human, and market relationships. This structure is sometimes not apparent because of its numerous sources of noise or random behavior and due to its often lengthy time delays between cause and effect.

The second aspect to be noted is the distinction between the achievements that are apparent to the organization and those which are real. The

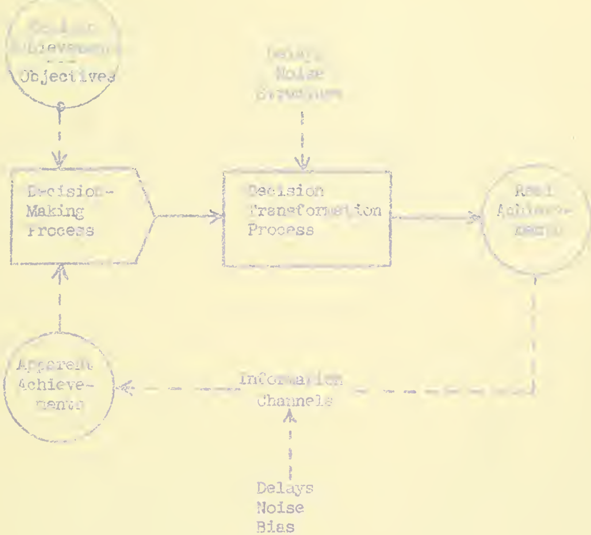

Figure 1. Control System Structure of Organizations

real situation is translated into the apparent through information and communication channels which contain delays, noise, and bias. These sources of error may be the inadvertent features of an organization's communication system, or they may result from the chosen characteristics of a data-processing system which sacrifices accuracy for promptness. In any event, however, the bases of actual decisions in an organization may be assumptions which may not fit the situation in fact.

The [illegible] feature of the diagram is that the decision-making process is viewed as a response to the gap between objectives of the [illegible]

[illegible] goal-seeking [illegible] in all organizations and in every subsystem of the organization. At any level of an organization, many similar decisions are being made. The real problem of the management control system designer is to recognize these multiple decision loops and their interrelationships, and to design policies and an organizational structure that will tie these activities into progress toward total organization objectives.

The fourth characteristic of Figure 1 is the continuous feedback path of decision-results-measurement-evaluation-decision. It is vital to effective system design that each element of this feedback path be properly treated and that its continuous nature be recognized. Whether the decision in the system is made by the irrational actions or logical deductions of a manager or by the programmed response of a computer, the system consequences will eventually have further effects on the decision itself.

II. Industrial Dynamics -- Philosophy and Methodology for Control System Design

Industrial Dynamics is a philosophy which asserts that organizations are most effectively viewed (and managed) from this control system perspective. It is also a methodology for designing organizational policy. This two-pronged approach is the result of a research program that was initiated and directed at the M.I.T. School of Industrial Management by Professor Jay W. Forrester. The results of the first five years of this program are described in Professor Forrester's book, Industrial Dynamics,

[illegible] problems.[1]

Industrial Dynamics recognizes a common systems base in the flow structure of all socio-economic-industrial-political organizations. This perspective ties the segmented functional aspects of formal organizations into an integrated structure of varying rates of flow and responsively changing levels of accumulation. The flow paths involve all facets of organizational resources -- men, money, materials, orders, and capital equipment -- and the information and decision-making network that links the other flows.

Industrial Dynamics views decisions as the controllers of these organization flows. Such decisions regulate the rate of change of levels from which the flows originate and to which they are sent. In the flow diagrams drawn as part of an Industrial Dynamics study, decisions are even represented by the traditional control valve symbol of the engineer. Figure 2 shows such a decision, based in part on information about the contents of the source level, controlling the rate of flow to the destination level.

The system structures and behavioral phenomena that are studied by the Industrial Dynamics methodology are present at all levels of the corporation. The top management of the firm is involved in a system that can be studied and aided in the same manner as the middle management of the organization, and again in the same fashion as the physical operating system of the plant. The potential payoff from changes derived from

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[1]Jay W. Forrester, _Industrial Dynamics_ (Cambridge: The M.I.T. Press, 1961).

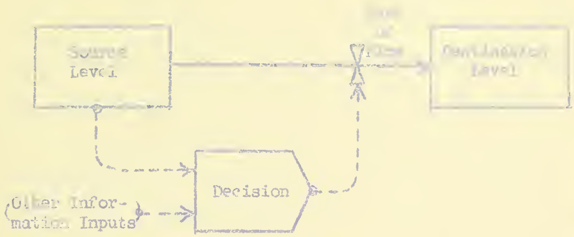


Figure 2. The Decision as a Controller

systems studies increases greatly, however, as the study is focused higher up in the organization. For all studies the pattern of forming a dynamic verbal theory, developing mathematical equations, computer simulation of the model, and derivation of improved policies is followed. The problems encountered in these phases do not significantly change as we move from the bottom to the top of an organization. Only during the final stage of implementation of system change does the problem complexity get significantly greater the higher the level of organization involved. But the impact of improved corporate-level policy on company growth, stability, and profitability can readily justify this added effort to renovate top management policy making.

III. Problems of Management Control Systems

The preceding discussion has focused on the nature of organizational problems as management control system problems, and on the intended applicability of Industrial Dynamics to these problems. Observation of several different types of management control systems and a survey of

[illegible] lead to a belief that [illegible] approach to control system design is needed. The traditional approaches to management control systems have mushroomed in number and sophistication of applications as operations research and electronic data processing have developed during the post-war era. Although these systems have made significant and successful inroads, many fail to cure the problems for which they were designed; other management control systems even amplify the initial difficulties or create more significant new problems. All this is taking place even as we derive enhanced but misplaced confidence in the systems.

Several examples will help to illustrate these problems and lead us to some findings about the design of management control systems.

Systems Inadequate for Their Problems

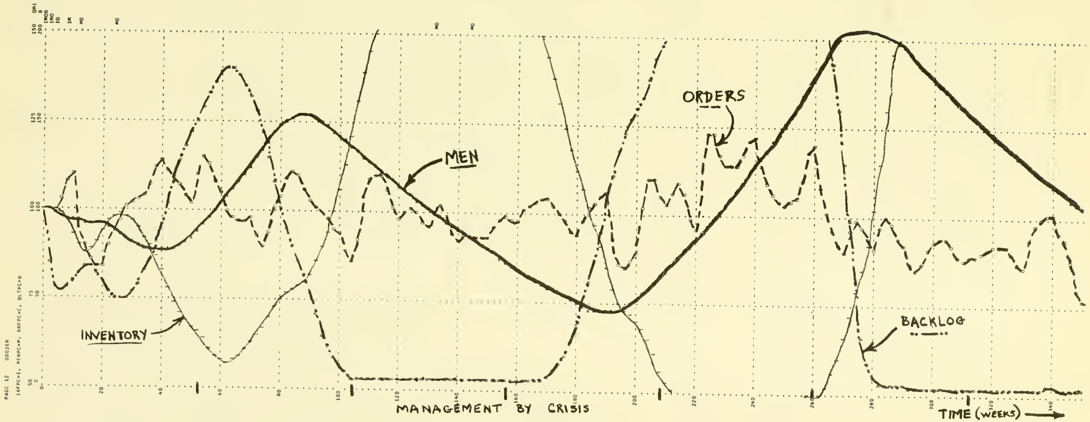
Sometimes the management control system is inadequately designed for the problem situation. In such a case the control system may improve performance in the trouble area, but be far short of the potential gains. At times the limited effectiveness may transform a potentially major benefit to the company into but a marginal application.

A Production-Inventory-Employment Control System

As an example, let us take the case of an industrial components manufacturer who initially has no formal production-inventory-employment control systems. Such a firm operates by its response to current problems. It follows the example of the firemen trying to use a leaky hose -- as soon as one hole is patched up, another leak occurs elsewhere. A company operating in this manner does not keep sufficiently close tabs on changes in sales, inventories, backlogs, delivery delays, etc. Rather, when

customer complaints build up on company delivery performance, people will be hired to increase production rate and repair the inventory position. Similarly, when a periodic financial report (or the warehouse manager's difficulties) shows a great excess in inventory, workers will be laid off to reduce the inventory position. Despite the obvious faults, the majority of our manufacturing firms have these problems. The dynamic behavior of such a firm (as here illustrated by simulation results of an Industrial Dynamics model) has the appearance of Figure 3, with wide swings in sales, inventories, employment, order backlog, and correspondingly in profitability. The potential for a well-designed management control system in such a firm is enormous.

The traditional approach (some may prefer calling it the "modern approach") to the design of a control system for such an organization will recognize that: (1) better information on sales is necessary; (2) such information should properly be smoothed to eliminate possibilities of factory response to chance order-rate variations; (3) inventories should be periodically (perhaps even continuously) checked, and reorders generated when needed to bring stocks into line with target inventories; (4) order backlogs should not be allowed to drift too far from the normal levels; and (5) work force should be adjusted to meet the desired production rate that stems from consideration of current sales volume and the manufacturing backlog situation. Using our earlier company model, we can readily build into the model a management control system that incorporates all these features. The modeled company would then be a leader in its use of management control techniques. And, as Figure 4 illustrates, the company would have benefited by this approach. With the new control

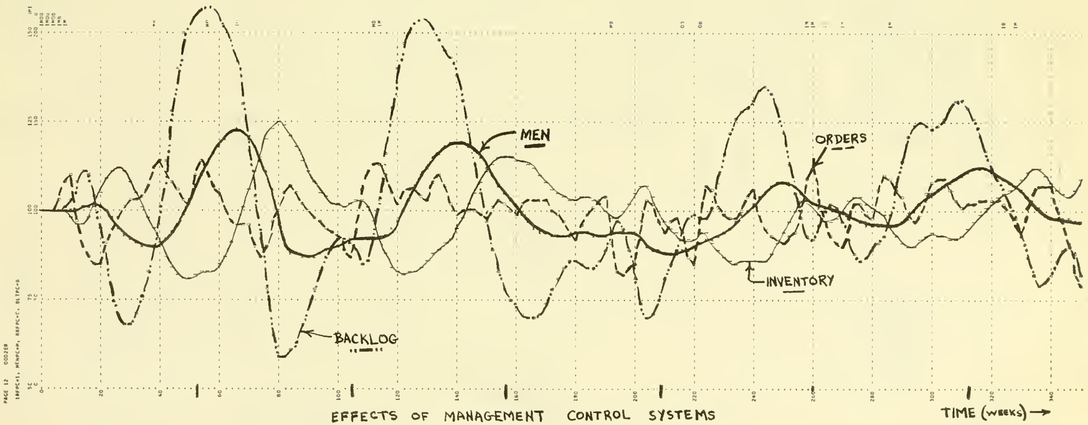

ORDERS
MEN
INVENTORY
BACKLOG
MANAGEMENT BY CRISIS
TIME (WEEKS)

system installed. Fluctuations in the business have in general been reduced in magnitude as well as periodicity. Yet the basic dynamic pattern observed in the earlier diagram is still present -- periodic fluctuations in sales, larger ones in inventories, and corresponding variations in production rate and work force. The latter situation is similar in character to that which we encountered at the Sprague Electric Company at the beginning of our Industrial Dynamics study program with them several years ago.

Let us briefly review their case. The Sprague Electric Company is a major producer of electrical components, with an annual sales volume of approximately 75 million dollars. The particular product line which was selected for Industrial Dynamics research is a relatively mature industrial component, developed by Sprague several years ago and now past its market introduction and major growth phases. The principal customers of the product are manufacturers of military and high-grade consumer electronic systems. The industry competition is not price-based, but is rather dependent on product reliability and delivery time.

The work structure of the company, including its inventory and manufacturing control aspects, is diagrammed in Figure 5. Orders arrive from the customers, and a determination is made as to whether or not they can filled from existing inventories. Orders for those catalogue items not ordinarily stocked, or for those which are currently out of stock, enter into the backlog of manufacturing orders. The customer orders for which inventory is in stock are processed and shipped from inventory.

The inventory control system of the company attempts to maintain a proper inventory position for the product line. Target inventories are


MEN
ORDERS
INVENTORY
BACKLOG
EFFECTS OF MANAGEMENT CONTROL SYSTEMS
TIME (WEEKS) →

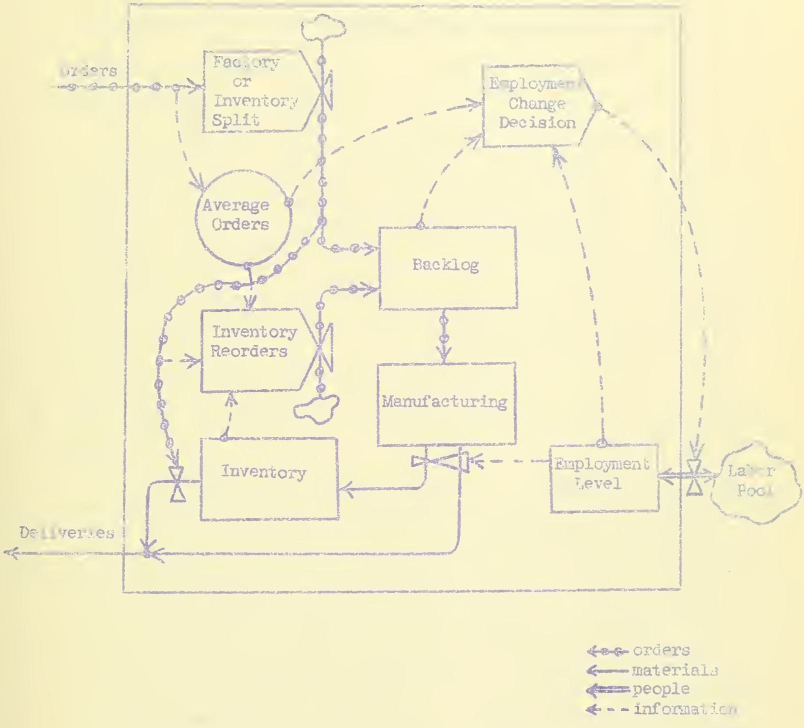


Figure 5. The Manufacturer's Organization Structure

adjusted to take into account average sales, and inventory reorders are generated to reflect the shipping rate from inventory and the desired inventory corrections. The orders for inventory replacements enter into the manufacturing backlog.

Production rate in the company is determined by the level of employment

with manufacturing output [illegible] in the [illegible] or [illegible] reflection of the relative production order backlogs. Control of unit backlog size and employment level is attempted by means of the employment change decision of the company.

As the curves of Figure 4 demonstrated, inventory, backlog, and employment all had sizable fluctuations, despite the existing controls in these areas. They seem to reflect, with some amplification, the variability in incoming orders. Given this situation of fluctuating sales, the traditional management control designer would either express satisfaction with the system performance or perhaps seek additional improvement by parameter adjustment. Neither approach would get at the source of the difficulties, and this source is not the fluctuations in incoming customer orders.

To determine the real system problem, let us examine our next diagram. Here we have duplicated the manufacturer's organization of Figure 5 and added a representation of the customer sector of the industry. The customers receive orders for military and commercial electronic systems. These are processed through the engineering departments, resulting in requirements for components. Customer orders for components are prepared and released as demanded by the delivery lead time of the component manufacturers. Delivered components enter into the system manufacturers' component inventories and are used up during production of the systems.

Having added this sector to our diagram, we now discover the presence of another feedback loop in the total company-customer system: changes in the company delivery delay will affect the customer release rate of new orders, which in turn will influence the company delivery delay. This

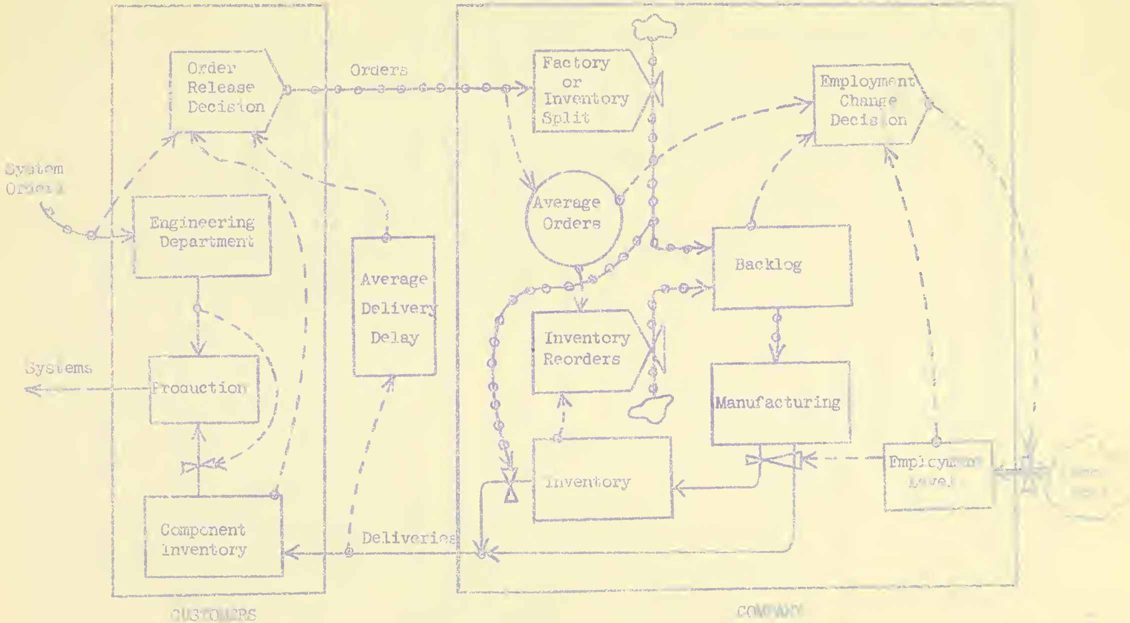


Figure [illegible]. Company-Customers System

loop amplifies the [illegible] problems of the company, being able to transform slight variations in system orders into sustained oscillations in company order rate, producing related fluctuations in company inventories, [illegible] employment, and profits

Let us follow through a possible dynamic sequence that will illustrate the full system interactions If, for any reason, system orders received by the customers temporarily increase, the customers will soon pass this along to the component supplier as an order increase Since, even under ordinary circumstances, weekly fluctuations in order rate to the component manufacturer are sizable, some time will elapse before this order rate change is noticed. In the meantime, the component manufacturer's inventory will be somewhat reduced, and the order backlog will be increased Both of these changes tend to increase the delivery delay The smaller inventory allows fewer incoming orders to be filled immediately; the larger backlog causes a longer delay for the now increased fraction of orders that must await manufacture. As the customers become aware of the longer lead time, they begin to order further ahead, thus maintaining a higher order rate and accentuating the previous trend in sales

Eventually, the component manufacturer notes the higher sales, larger backlog, and lower inventory, and begins hiring to increase his factory employment. The employment level is set higher than that needed to handle the current customer order rate, so that backlog and inventory can be brought into line As the increased work force has its gradual effect on inventory and backlog, the changes tend to reduce the delivery time The information is gradually fed back to the customers, lowering the order rate even below the initial value This set of system interactions can

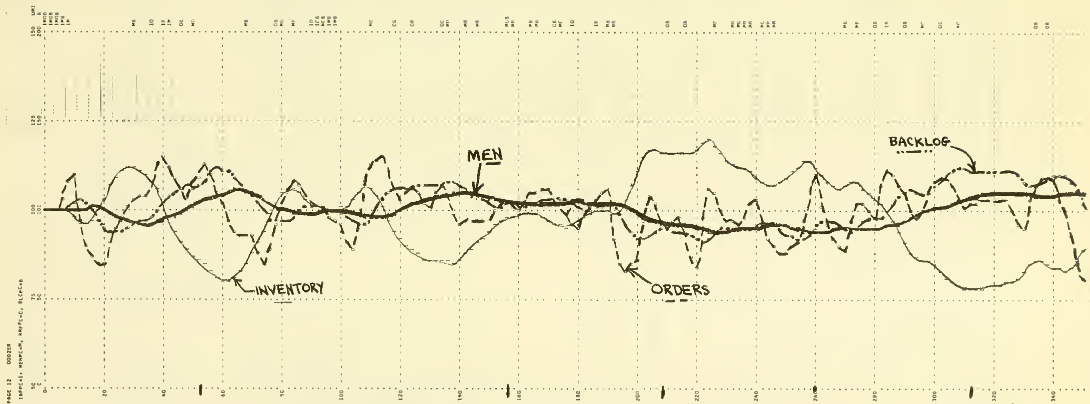
produce order rate fluctuations unrelated to the basic demand patterns for the customer products.

To dampen the fluctuations in customer order rate, the component manufacturer must control not inventory or backlog or employment, but rather he must stabilize the factory lead time for deliveries. This can readily be accomplished once the nature of the need is recognized. System behavior can also be improved to a great extent when the component manufacturer becomes aware that his inventory control system does not really control inventory, but it does contribute to production overshoots of any change in orders received.

The details of the Sprague case, the model for its study, and the new policies now being implemented at Sprague are discussed fully in Chapters 17 and 18 of Industrial Dynamics. It is sufficient for our purposes to show the effects of the new policies applied to the same situation shown earlier in Figure 4. The curves shown on the next graph demonstrate a higher degree of stability achieved in all variables except inventory, which is now being used to absorb random changes in sales. In particular, the employment swings have been dampened significantly. The simulation results forecast significant benefits to the company deriving from the application of this new approach to management policy design. Our experiences during the past year of system usage at Sprague seem to support the initial hypotheses, and the product line is currently benefiting from higher productivity, improved employment stability, higher and smoother sales, and lower inventories.

The Control of Research and Development Projects

Another area in which the traditional approach to control system



EFFECTS OF INDUSTRIAL DYNAMICS POLICIES

design has proven inadequate in the management of research and development projects. The intangibility, lack of precise measurement, and uncertain character of R and D results are partly responsible for this failure. But a more basic lack of system understanding has implications of even greater significance. All systems of schedule and/or budget control that have been tried will now have failed to achieve success in R and D usage. These techniques have included Gantt charts, milestone schedules, and computerized systems of budgetary and manpower control.

The latest approaches to control of research and development projects are based on PERT (Program Evaluation Review Technique) or PERT/COST. The management control systems implied by the methods used can be represented by the diagram of Figure 8. As shown here, the basis of the current

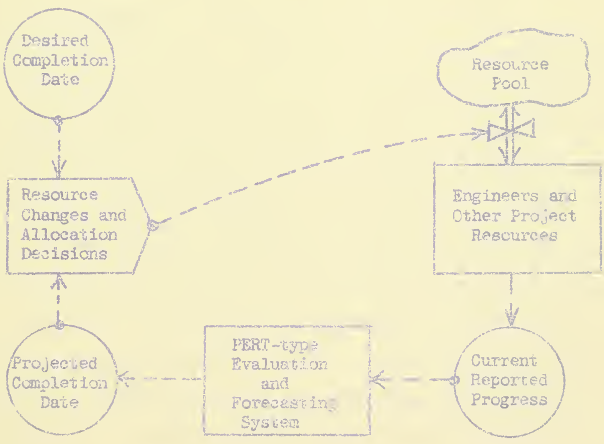


Figure 8. Assumed Basis of Current R and D Project Controls

sophisticated methods in a single-loop system in which the difference between desired completion date and projected completion date causes decisions to change the magnitude or allocation of project resources (manpower, facilities, equipment, priorities). As these resources are employed, they are assumed to produce the progress that is reported during the project. These reports are processed through a PERT-type evaluation and forecasting system to create the projected completion time.

But the design of a management control system based on such a set of assumptions is doomed to failure, since some of the most vital aspects of the real system have been excluded from the underlying analysis. For example, the lack of tangible, precise measurement sources is entirely ignored. Yet these factors contribute much of the error between the <u>real</u> situation in the project (its true scope and actual progress to date) and that which is <u>apparent</u> to those doing the engineering work.

Another part of the real system which appears to be ignored by current R and D control system designers is the human element in the project actions and decisions. The attitudes and motivations of the engineers and managers, their knowledge of the schedules and current estimates in the project, the believed penalty-reward structure of the organization -- all affect the progress and problems that are reported upward in the organization. Furthermore, these same factors even affect the rate of real progress toward project objectives. All systems of measurement and evaluation (in R and D, manufacturing, government, universities, or what-have-you) create incentives and pressures for certain actions. These interact with the goals and character of individuals and institutions to produce decisions, actions, and their results. For example, a system which compares "actual to budgeted

expenditures" creates an incentive to increase budgets, regardless of need, and to hold down expenditures, regardless of progress; one which checks "proportion of budget spent" creates pressures on the manager or engineer to be sure he spends the money, whether or not on something useful. The presence of such factors in research and development ought to be recognized in the design of systems for R and D control.

Adding these two additional sources of system behavior to the earlier diagram produces the more complete representation of a research and development system that is pictured in Figure 9. But even this is an incomplete representation of the complex system which interrelates the characteristics of the product, the customer, and the R and D organization. A proper characterization of research and development projects must take into account the continuous dynamic system of activities that creates project life cycles. Such a system will include not just the scheduled and accumulated effort, costs, and accomplishments. Rather, it will encompass the full range of policies and parameters that carry a research and development project from initial perception of potential need for the product to final completion of the development program. The fundamental R and D project system is shown in Figure 10, from which we have developed an Industrial Dynamics model of research and development project dynamics.

Some of the results of simulation studies of this model are of particular interest to designers of management control systems. They demonstrate the importance of taking cognizance of the complete system structure in attempting to create and implement methods of system control. For example, one series of simulations of the general project model was conducted in which only the scheduled project duration was changed in the

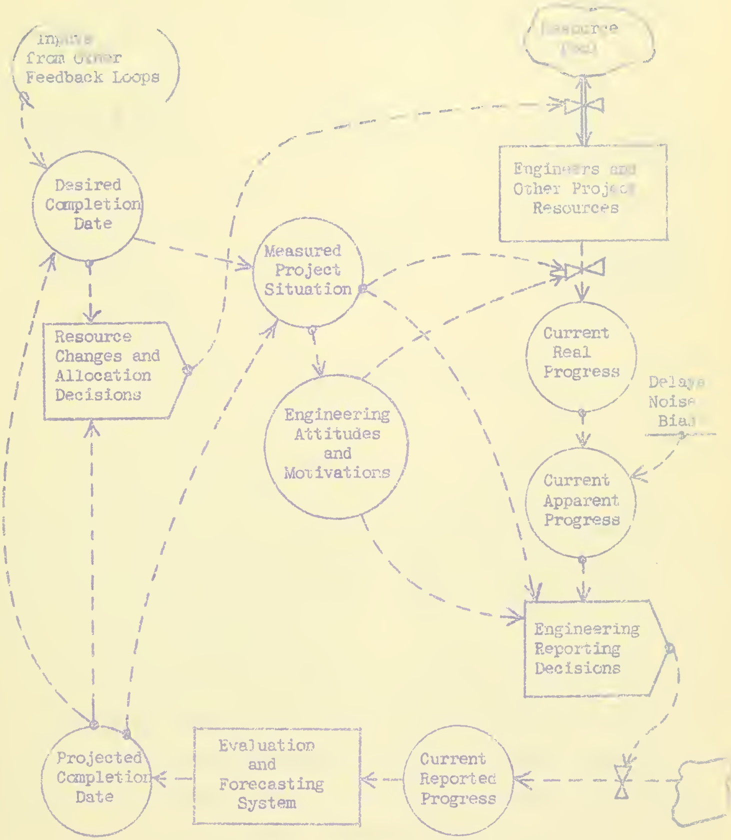


Figure 9 More Complete Representation of R and D System

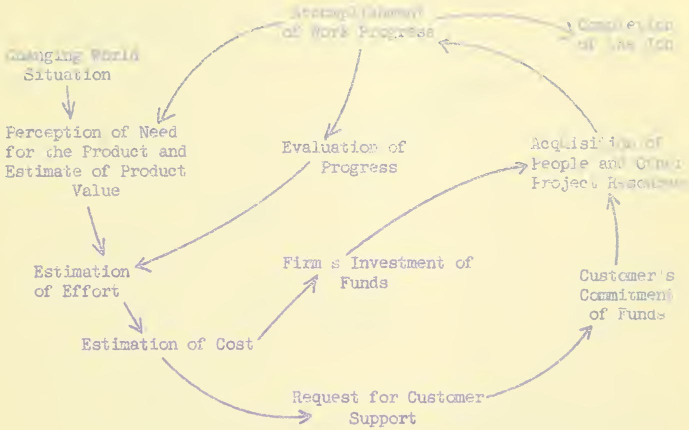


Figure 10. Dynamic System Underlying R and D Projects

various runs. Within the model the effort allocation process <u>attempts</u> to complete the project during this scheduled period. However, the actual completion dates of the projects seem only remotely responsive to the changes in desired completion time.

Figure 11 demonstrates the nature of this response, using the data of four model simulations. The horizontal axis is an index of the scheduled project duration as a percentage of the maximum schedule used; the vertical axis shows actual completion time in a similar percentile manner. If changes in schedule produced corresponding changes in actual completion dates, the curve of results would have followed the diagonal "perfect response" line; that is, a 50 percent reduction in scheduled duration should produce a 50 percent reduction in actual duration, if control is

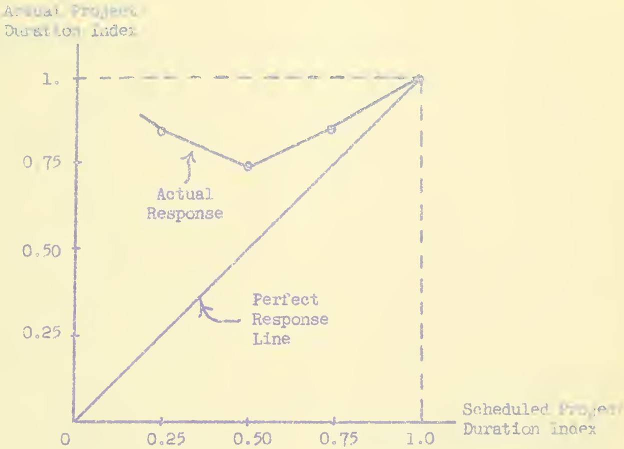


Figure 11. Scheduled vs. Actual Project Durations

perfect. But the actual response is far from perfect; a 50 percent schedule change effects only a 25 percent actual change. And at the extreme, the actual change is even in the opposite direction, taking longer to complete the urgent crash project because of the resulting organizational confusion and inefficiencies. Of course, this response curve does not present the data on the manpower instability, total project cost, and customer satisfaction changes that also accompany shifts in the project schedule.

Some of the implications of Figure 11 are more clearly presented by the next curve. Here the slippage in project schedule is plotted as a function of the scheduled duration, the points on the curve coming from the project model simulations. A completion time slippage of 242 percent

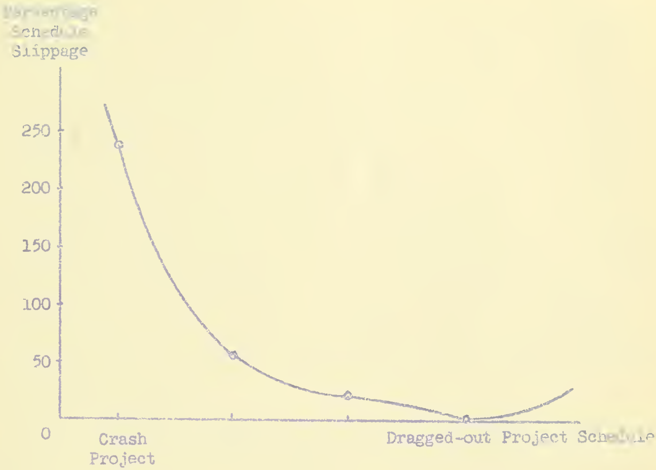


Figure 12. Schedule Slippage as a Function of Schedule

of schedule was incurred in the crash project, with a rapid decrease in this percentage completion date overrun as the schedule is dragged out. When the project is slowed too much, the slippage increases again as lack of enthusiasm induces further stretch-out during the project life.

The principal point made by these two illustrations is that many factors other than desired schedule determine the resultant actual schedule of research and development projects. Control systems for R and D which resort to schedule and effort rate control without full understanding of the system structure of projects are bound to be ineffective. The current PERT-based project control systems seem guilty of this error in design philosophy. In fact, many aspects of our government contracting program

[illegible] [illegible] policies with attendant cost overruns. For example, increased risk-taking (i.e., greater willingness to invest company funds prior to contract receipt) and higher bidding integrity by R and D companies would act in the best interests of the government customer of research and development. However, our simulation studies show that neither policy is in the short-term best interests of the R and D companies, under existing government regulations and practices. Thus the contracting policies, a government control system for R and D procurement, act to the detriment of national objectives by inducing company behavior which produces unsatisfactory project outcomes.[2]

The proper design of research and development control systems, for both company and customer, should take into account three things: (1) the source of internal action, information, and control in a project is the individual engineer; measurement and evaluation schemes and the internal penalty-reward structure must be designed with him in mind; (2) the observed results of research and development projects are created by a complex dynamic system of activities, which interrelates the characteristics of the product, the customer, and the R and D firm; control systems which ignore vital aspects of these flows cannot succeed; (3) institutional objectives of R and D companies (profits, growth, stability) can be aligned with the objectives of government customers; procurement policies

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[2]A general theory of research and development project behavior, a model of the theory, and extensive simulation studies of parameters and policies influencing R and D outcomes are reported in the author's book, _The Dynamics of Research and Development_, to be published later this year.

constitute the system of control which can attempt to restore this align-
ment.

Systems Creating New Management Problems

The two control system areas discussed above were intended to demonstrate that many management control systems are designed in a manner that makes them inadequate to cope with the underlying problems. In each example, however, certain aspects of the systems were described which actually aggravated the existing problems. In the Sprague case, the inventory control system amplified sales changes to create wider swings in production and employment than actually existed in orders received from the customers. Our discussion of research and development project control indicated that government contracting policies often create resulting behavior that is contrary to the government's own interests. Other examples can be presented which have similar effects: the attempt to achieve management control leads to situations in which initial difficulties are amplified or significant new problems are created.

Problems of Logistics Control

One apparent instance of this type occurs in the Air Force Hi-Value Logistic System. This inventory control system was developed over a long period of time at great government expense by some of the nation's most sophisticated control system designers. The Hi-Value System is intended to provide conservative initial procurement and meticulous individual item management during the complete logistic cycle of all high-cost Air Force material. Yet an Industrial Dynamics study of this system by a member of the M.I.T. Executive Development Program concluded that the

system behavior can result in periodic overstatement of requirements, excess procurement and/or unnecessary repair of material, followed by reactions at the opposite extreme.[3] These fluctuations produce undesirable oscillations in the repair and procurement work loads and in the required manpower at Air Force installations, supply and repair depots. The study recommended changes in policy and information usage that tend to stabilize the procurement system behavior.

Quality Control Systems

A commonly utilized management control system has as its purpose the control of manufacturing output quality. The feedback system apparent to the designers of such quality control systems is pictured in Figure 13.

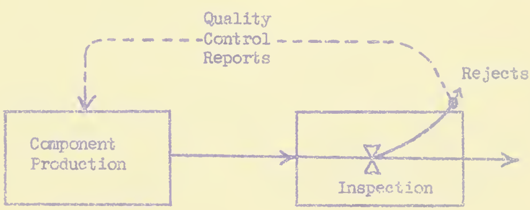

Figure 13. Theoretical Quality Control System

Component parts are produced by a process that has a certain expected quality or reliability characteristic. The parts are inspected for flaws

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[3] Max K. Kennedy, "An Analysis of the Air Force Hi-Valu Logistic System: An Industrial Dynamics Study" (unpublished S.M. thesis, M.I.T. School of Industrial Management, 1962).

and rejects discarded or reworked. Statistically-designed control charts determine when the production process is out of control, and reports are fed back to production to correct the problem sources.

The effectiveness of such quality control systems becomes questionable when we view the performance curves generated by a typical system. Figure 14 plots component production rate and inspection reject rate over a period of two years. Wide periodic swings in reject rate produce violations of the control system tolerance limits which cause machine adjustment

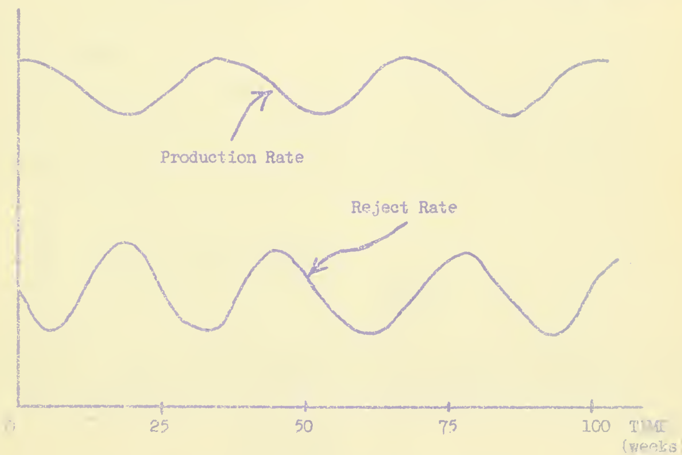

Figure 14. Quality Control System Performance

in production and temporarily lower production rates. But what causes the oscillations in the reject rate? Its periodic nature suggests seasonal fluctuations in production quality, often strangely encountered in many manufacturing plants. The manager has almost no way of checking the

validity of such an assumption. Therefore, since the assumption seems reasonable, it would probably be accepted under most circumstances.

This situation illustrates one of the key problems in quality control --the lack of an objective confirming source of information. We are in a more favorable position to understand the phenomenon, however, since the results were produced by a computer simulation. The surprising fact is that the actual production quality was held constant, without even random variations, throughout the two years of the run. This means that the oscillations of reject rate and production shown in Figure 14 are not responses to outside changes, but rather are internally created by the behavioral system.

Let us examine a more complete picture of the total factory system, as shown in the next diagram. Components are produced, then inspected, rejects being discarded. The accepted components are forwarded to an

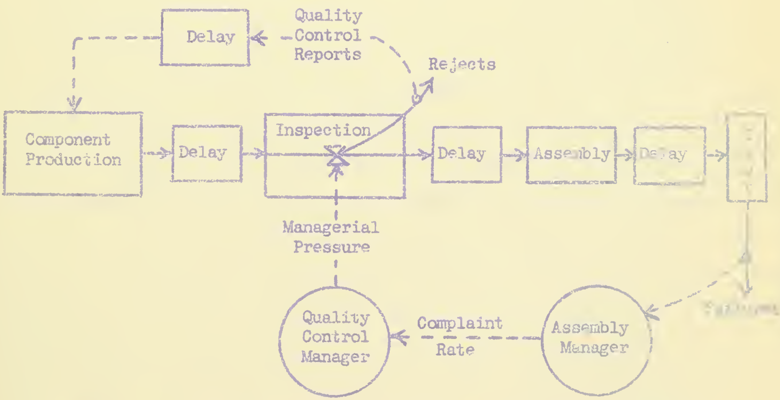

Figure 15. More Complete Representation of Quality Control System

assembly operation, where they enter into the manufacture of complete units. In an electronics plant, for example, the component production and inspection might correspond to a grid manufacturing operation, with the assembly operation putting together complete electronic tubes. When the tube is put through a life test, tube failure and the source of failure are far more obvious than are the grid imperfections during the component inspection. Should too many imperfections get through component inspection, eventual tube failure rate will produce complaints by the assembly manager to the quality control manager. As these complaints continue to build, the quality control manager puts pressure on his inspectors to be more careful and detect more of the poor grids. In response to this pressure, the inspectors reject far more grids. Without an objective measure of grid quality, the reject rate tends to be a function of subjective standards and inspection care. Under pressure from the manager, the inspectors will reject any grid which seems at all dubious, including many which are actually of acceptable quality. As the rejects rise, fewer poor grids enter the assembly process, thus causing fewer tube failures in test. The assembly manager's complaints drop off and, in fact, soon switch to a concern for getting more grids for his assembly operation. Without pressure from the quality control manager and with counterpressure to get more grids to the assembly operation, the grid inspectors tend to slacken gradually their care and their reject standards. Eventually, the number of rejectable grids getting into the tube assembly creates the problem of tube failures again, and the cycle repeats. Given normal delays in such a process, the entire cycle takes on a seasonal appearance. Thus, a system intended to assure control of product quality actually

creates serious fluctuations of rejects, component production, and tube failures, all attributed to unknown factors "out of our control".

The consequences of such a situation are even more serious when the inspection output is distributed to eventual customers through the normal multi-stage distribution system. In this case the customer complaints and store returns also affect sales. These influences combine after a long delay to produce significant top management pressure on the quality

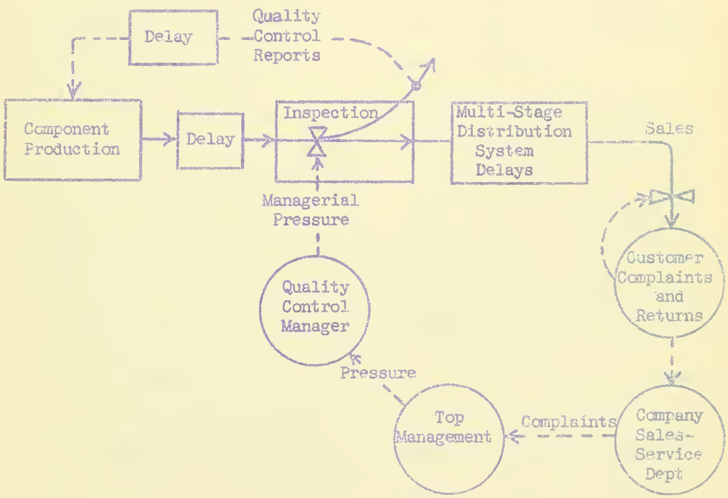

Figure 16 Total Quality Control System

control manager in reflection of a situation which existed many months before. In both Figures 15 and 16, the quality control manager's response is a key to system behavior. Here the manager of the formal quality control

system is itself the most important aspect of the total system of quality and production control.

IV. Some Principles of Management Control System Design

The examples discussed represent a wide range of management control systems. Study of these applications produces some general principles of management control system design.

A. The key to effective control often lies outside the boundaries of conventional operational control systems; in fact, it is sometimes outside the formal boundaries of the company organization

Too many organizations give up altogether too soon the battle for mastering a management problem caused by factors apparently "out of our control". The cyclic swings in customer orders in the production-inventory case, government changes in project funding of research and development, seasonal variations of product reject rate in the quality control problem are all examples of such factors. Yet in each case successful control system management rests within the access of company policy.

In the Sprague case the system requiring control included the ordering decisions of the customer, certainly not part of Sprague's formal organization. But the basis for system control exists in the stabilization of the input to the customer decision, the component delivery delay. Again, project success in R and D is strongly influenced by company integrity and risk-taking. Yet customer, not company, policy can be redesigned to achieve desirable company behavior. And the key to quality control involves recognition of the total

system of product flow to assembly (or to customers) and the resulting feedback of complaints and pressures.

<u>The boundaries of a management control system design study must not be drawn to conform with organizational structure merely because of that structure.</u> System boundaries cannot ignore vital feedback channels for information and action if the system is to be effective.

B. The proper design of management control systems often requires inclusion of the effects of intangibles; in particular, the role of decision makers who are part of the total system of control must be treated carefully.

Control system designers who are working with computers often have as their end product a computer model for calculating (or searching for) an optimal control decision. Yet while being willing to model a decision for a machine, they seem unwilling to include in their studies any models of man--of human decision-making within the control loops. In the production-inventory control case, the modeling of aggregate customer decision-makers is a vital part of the system. Our second example emphasized that a properly designed R and D control system should be based on models of engineer and manager decision-making in both the company and customer organizations. Finally, we observed that the decision-making and responses of both managers and inspectors are crucial aspects of the quality control case.

These illustrations emphasize the usual failure to recognize and cope with the nature of human response in organizations. The decision-makers, single or aggregated--their motivations, attitudes,

pressures, models of response--must be included in management control system design. <u>The man (and manager) is part of the system of control, and management control system design must be viewed as a form of man-machine system design.</u>

C. A true understanding of total system basis and system behavior can permit effective design of both operational control systems and top management policy, without differences in philosophy or methodology of approach. In fact, most significant control system applications inherently require supra-functional or multi-departmental organization.

In the Sprague case, for example, successful control involved consideration of such aspects as customer service (marketing), inventory and production rate (manufacturing), and employment policies (personnel). Thus what often gets treated as a middle-management problem becomes resolvable only at the top policy-making level of the firm. The important elements in research and development tend not to be middle-management concerns for schedules, but rather top management policy affecting investment planning, customer relations, and company-wide attitudes. Management control systems can therefore seek to achieve the major goals of the organization as a whole, and not just the sub-optimizing aims of individual segments. A great present hazard, in fact, is the common planning and programming of control systems at the wrong level of the company, by people who lack total system perspectives and the authority to achieve broad system integration.

The Industrial Dynamics program has demonstrated the possibilities of examining and treating system problems of great variety and scope

of complexity. We have dealt with many situations in which stabilization was needed and more recently with other cases in which balanced growth was the objective of the policy design efforts. The potential advantages to companies who pioneer in this work are significant and may become the basis of our future industrial competition. In this regard, it seems fitting to close with the implied advice of the Japanese scholar who said: "When your opponent is at the point of striking you, let your mind be fixed on his sword and you are no longer free to master your own movements, for you are then controlled by him."

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[1]Takawan, as quoted by Charles H. Townes, "Useful Knowledge", *Technology Review*, January, 1963, p. 36

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